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Assessment of domestic water demand and supply in the upper Pravara dam command area using the WEAP Model

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Abstract
This study focuses on assessing the water demand and supply scenario in the command area of the Upper Pravara Dam located in Maharashtra, utilizing the Water Evaluation and Planning (WEAP) model. The catchment area was chosen to evaluate domestic water needs and availability. The assessment provides insights into both current and projected domestic water requirements, using the WEAP system as a planning framework.
To conduct this evaluation, various datasets were used, including population figures from Census 2011 and UIDAI, dam-related information, per capita water usage, canal distribution, irrigated and culturable command areas, and other relevant records obtained from the Upper Pravara Canal Division. These inputs were critical in estimating future water demand and shaping effective planning strategies.
The analysis was carried out for two towns within the region Sangamner and Akole. According to model projections, domestic water demand in the year 2020 was around 2.97 million cubic meters (Mm^3) for Sangamner and 0.58 Mm^3 for Akole. By the year 2050, these figures are expected to rise to 6.03 Mm^3 and 1.17 Mm^3, respectively.
The findings confirm that the WEAP model serves as a practical tool for long-term water resource planning in the Upper Pravara basin, helping to forecast and manage water requirements over the next three decades.

Keywords: WEAP, catchment area, water demand, water requirement, water resource planning

1. Introduction
Water is a important resource essential for human progress. It supports agricultural productivity, industrial activities, and sustains the growth of urbanization. To meet the increasing demand for drinking and industrial water, both groundwater and surface reservoirs serve as crucial sources of supply. In this study, catchment area of Bhandardara and Nilwande dam is about 202 Sq.km. The Pravara River often experiences flooding during the rainy season. Bhandardara dam is constructed across the river at upper basin. Due to construction of Nilwande dam flood occur in Pravara River basin has been stop.
Assessing the impacts of ecosystem degradation—from environmental rehabilitation to the social and economic growth of a region—requires a thorough understanding of the area, especially the key factors and agents that shape its ecological characteristics.
The project refers that, proposed and sanctioned Nilwande dam can carry 8.32 TMC water. The Upper Pravara Project Nilwande dam has gross command area of 1,11,090 ha, culturable command area of 86,100 ha and irrigated area about 64,260 hectares. The total command area up to the proposed dam site is 323.95 sq.km including the catchment area of 121.74 sq.km of Bhandardara dam, an upstream existing project.

Table 1: Area under Canals

Canals	G.C.A. ha	C.C.A ha	Irrigation ha
Upper Pravara left bank canal system	75870	58800	43886
Upper Pravara right bank canal system	35220	27300	20374
Total Area	1,11,090	86,100	64,260

For the present study, the Water Evaluation and Planning (WEAP) tool was used. This model, created by the Stockholm Environment Institute (SEI), is intended to assist in analyzing and managing challenges related to water resource development and planning. WEAP is applicable in both agricultural and urban settings, allowing for comprehensive evaluation of issues such as water demand across sectors, conservation practices, allocation and water rights, reservoir operations, streamflow management, ecosystem sustainability, and cost-benefit assessments of proposed projects (SEI, 2001).

In this present study, the WEAP21 model was used to simulate water resources in the Pravara River Basin and evaluate the water balance under increased service levels due to increased population, increased irrigation development and expanded industrialization, and to determine water allocation among users. The modelling process consists of two main components, namely, the supply and demand components. The supply component comprises of the hydrological analysis of the river and the demand component comprises a growth projection based on domestic, livestock, industrial, environmental flow requirements (EFRs). The proposed framework employs the Water Evaluation and Planning (WEAP) system to assess both present and future water demand, as well as the associated supply gap. Simulation scenarios indicate that this gap can be effectively addressed through dynamic resource allocation, provided certain assumptions are considered—such as population growth and fluctuations in demand due to weather variations. In this way, the framework serves as a valuable tool for making informed decisions regarding water supply management. (Arfa Saleem and Imran Mahmood., 2021) [2]. The scenarios include High Population Growth Rate as 3.5% and Low Population Growth Rate as 1.5%.

The primary aim of this study was to utilize WEAP21 as a Decision Support System (DSS) for effective planning and allocation of water resources in the Nilwande catchment area to predict the water availability and future water demands in command area and analysis of the supply and demand of water in 2050 based on population.

2. Materials and Methods

2.1 Study Area

The study area covers the stretch from the source of the Pravara River up to Akole tehsil, located between 73°37′E to 74°05′E longitudes and 19°28′N to 19°39′N latitudes. It includes the Nilwande Dam and its canal systems along the Pravara River. The dam, officially known as the Upper Pravara Nilwande Dam, stands at an elevation of 593 m above mean sea level, with a structural height of 73.91 m (242.5 ft) above its lowest foundation and a length of 583 m (1,913 ft). Nilwande is the second-largest dam on the Pravara River after the Bhandardara Dam. The project incorporates two canals: a right-bank canal extending 102 km and a left-bank canal measuring 85 km in length.

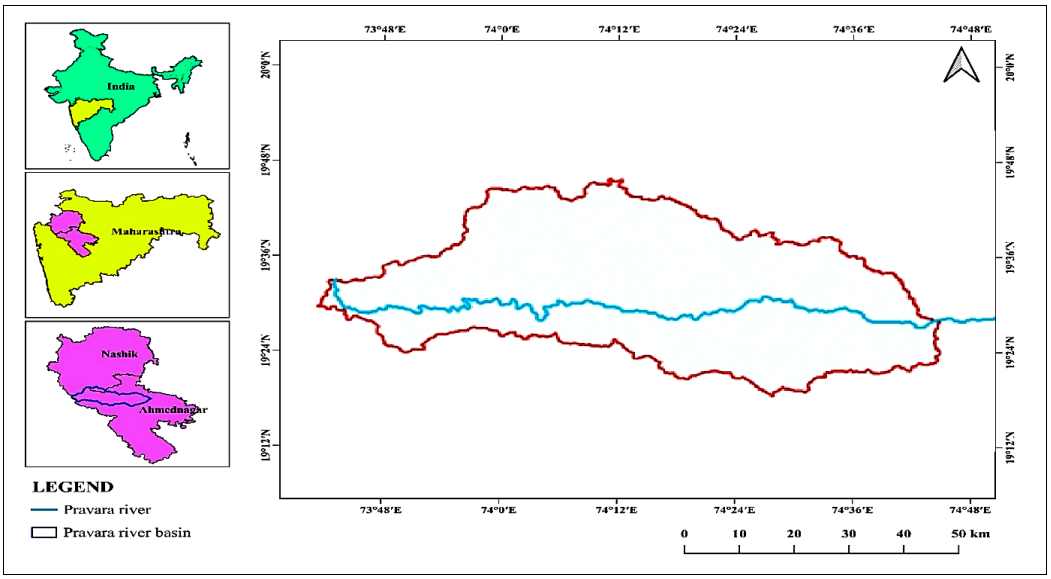

Fig 1: Map of Study Area

2.2 Climatological Characteristic

The district's climate is marked by hot summers and remains generally dry, except during the southwest monsoon season. The mean daily maximum temperature is about 38.9°C and mean daily minimum temperature is 8.7°C. The average annual temperature in the study area is 28.30°C. The annual average rainfall in this study area is 508.9 mm.

2.3 Soil Characteristics

In the upper reaches of the Pravara River basin, the terrain is dominated by very shallow, excessively drained loamy soils on steep slopes. Moving from west to east across the south-central region, the landscape transitions into shallow, well-drained clay soils situated on moderate slopes. Toward the eastern side, extensive areas consist of deep, moderately well-drained fine soils on very gentle slopes. The southeastern portion is predominantly covered with slightly deep, somewhat excessively drained loamy soils on gentle slopes, along with slightly deep, well-drained, fine calcareous soils on very gentle slopes. The remaining areas are characterized by very shallow, excessively drained loamy soils on moderate slopes. The sediments reveal a good admixture of gravel, sand, silt with lesser percentage of clay (Joshi and Nagare 2009) [11].

2.4 Water Utilization

The amount of water available and its utilization for upper Pravara Dam is given in following table 2. (Upper Pravara Irrigation Division, Sangamner, Maharashtra)

Table 2: Availability of Yield and its Utilization

Sr. No	Particulars	M. Cum.	T.M.C
1	Water requirement of canal irrigation		
	Area under Flow Irrigation	191.14	6.750
	Area under Micro Irrigation	63.00	2.225
2	Lift irrigation requirement on reservoir	11.06	0.39
3	Water supply requirement of Sangamner and Akole	13.15	0.46
4	Requirement of high-level canals	7.77	0.27
5	Deduct evaporation losses	8.26	0.29
	Total utilization Proposed	294.38	10.385

2.5 Population

2.5.1 Population Projection

Two approaches were used to estimate population growth: the arithmetic growth method and the expression builder method. The arithmetic growth method was specifically applied to project the population in the Nilwande catchment area for the period between 2001 and 2011. The formula for the arithmetic growth method is presented below.

$P = P_0 \times (1+\rho)^{(T - T_0)}$ ……3.1 (Albert Barlett,1993)

Where,
P = Projected population in number
Po = Baseline population in number
ρ = growth rate in percentage
T = Projected year
To = Baseline year

The Expression Builder is a "GrowthForm" function built into the WEAP model that helps project the population of the reference period (2021-2050). The Expression Builder in WEAP serves as a general-purpose tool that allows users to construct WEAP expressions by simply dragging and dropping functions and branches into the editing box. For projecting population during the reference period, the input data entered in the Growth Form field included the year of the most recent census (2011), the recorded population in 2011, and the estimated growth rates for the Sangamner and Akole regions.

2.5.2 Population Growth Scenario

A) Reference Scenario

Reference Scenario (*Ref.*) used to incorporate currently identifiable trends in development, water supply availability, water-use efficiency and other aspects. The Reference Scenario was coded as "Reference" (also meant Business-as-usual Scenario) and was outlined based on the continuation of current patterns. This scenario was allocated a 2.39% and 2.40% growth rate based on population growth rate for Sangamner and Akole.

B) High Growth Rate Scenario

The **High Growth Scenario (HG)** was designed as a "what-if" analysis to examine the impacts of rapid population growth coupled with increased domestic and municipal water demand, while applying only minimal demand-management measures. Under this scenario, the population growth rate was assumed to rise from 2.39% to 5%, thereby significantly influencing the projected water demand.

2.5.3 Sangamner

Sangamner city is located in the Ahmednagar district of Maharashtra. According to the 2011 Census, the town had a total population of 65,804, comprising 33,463 males and 32,341 females. The female sex ratio stood at 966 females per 1,000 males, while the child sex ratio was 831 girls per 1,000 boys under the age of six. The total number of households recorded in Sangamner was 13,218 (Census, 2011)

2.5.4 Akole

According to the 2011 Census, Akole Taluka of Ahmednagar district had a total population of 291,950, consisting of 147,880 males and 144,070 females. A total of 59,284 households were recorded in the taluka. The overall sex ratio was 974 females per 1,000 males. Of the total population, 3.4% resided in urban areas, while the remaining 96.6% lived in rural regions. The literacy rate was 88.6% in urban areas compared to 74.4% in rural areas. The sex ratio in urban Akole was 918, whereas in rural parts it was slightly higher at 976 (Census, 2011).

2.6 Data Collection

The process of data collection plays an important role in fulfilling the research objectives; therefore, careful attention was given to data sourcing, acquisition, and quality verification. An initial assessment of the modeling tool WEAP21 helped determine the essential datasets required for model development. These datasets were grouped into six major categories: (1) hydrology, (2) climate, (3) hydrometric data, (4) land use and land cover, (5) water supply, and (6) regional population and water use.

The data collection process started with determining data sources and accessing websites where data can be acquired on-line. Data sources include a variety of government agencies and local authorities; such as Survey of India, Census India, Upper Pravara Canal Division Sangamner, Maharashtra, Irrigation Department Maharashtra Government, Upper Pravara Dam Division, Central Water Commission New Delhi, Sangamner Municipal Cooperation, Akole Town Council, and Nimbral grampanchayt etc.

2.7 Water Demand and Supply

The domestic water demand for Sangamner and Akole tehsil in Pravara catchment area were analyzed using WEAP21 model.

2.7.1 Annual Demand in WEAP

The monthly demand reflects the volume of water required by a demand site for its utilization on a month-to-month basis. The total demand for a demand site (DS) is determined by summing the demands of all its lowest-level branches (Br).

Annual Demand = Total Activity Level ×Water Use Rate

It is required to input an activity level and a water use rate associated with that activity level. Monthly variation can then be described either with some user-defined expression or variation weighted by days in each month.

In the WEAP demand analysis, losses, reuse, and efficiency are treated as separate components. Water demand is estimated by multiplying the overall activity level by the corresponding water use rate. Within WEAP, Activity Levels serve as an indicator of social and economic activities, forming a key basis for demand assessment. Domestic water use is the most important, it has the highest priority. Sangamner city having water requirement is 100 l/p/c/d and Akole having 70 l/p/c/d.

Table 3: Demand-side variables

Variable	Unit	Description
Monthly demand (MD)	Mm^3	Monthly water demand of each site.
Population per Year (PPY)	Capita	Population variation according to Year
Population (P)	Capita	Yearly population of a demand site.

2.8 Supply Demand

Considering the water losses, supply demands vary. WEAP allocates water based on defined demand priorities and supply preferences. The allocation order determines the sequence in which water is distributed, reflecting the actual calculation process used by the model. Transmission links sharing the same allocation order are processed simultaneously during allocation

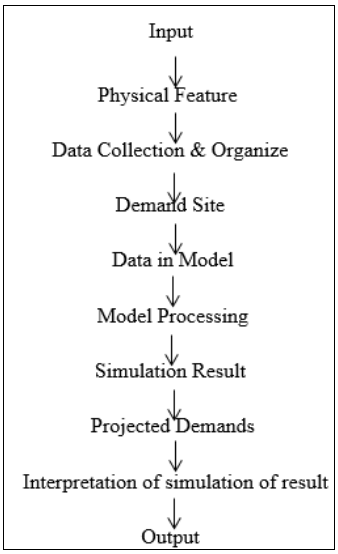

Fig 2: Flow Chart of WEAP Model Processing

3. Results and Discussion

3.1 Computing Water Use Rate

3.1.1 Population Growth Rate

The WEAP model was used to project the population of Sangamner and Akole for the reference year. As per census (2011) the population of Sangamner city was 65804. The growth rate was 2.39% and the projected population for Sangamner was found to be 83335. Similarly, as per census (2011) the population of Akole city was 18278. The growth rate is 2.40%, and the projected population for Akole was found to be 23166.

3.1.2 Reference Scenario (2021-2050)

The Reference scenario (2021 to 2050) contains the same data and structure as the Current account's year (2020). The only difference between 2020 and the following years 2021 to 2050, is the population growth in Sangamner and Akole city. As per census 2011 the population of Sangamner city was 65804 and as per Aadhar card holder the city population in 2020 was 81531. As per municipal cooperation of Sangamner the growth rate is 2.39% based on 2001 and 2011 census. So, after 30 year the population was expected as 165309. And the population of Akole city as per census 2011 was 18278 and as per Aadhar card holder the city population in 2020 was 22664. As per municipal cooperation of Akole the growth rate is 2.40% on the basis of 2001 and 2011 census. So, after 30 year the population was expected as 46092.

3.1.3 High Population growth (2021-2050)

Population growth is the primary factor influencing future water demand, High growth rate population is considered as 2.39% to 5%. It was predicted that the population of Sangamner city in 2021 is 85607 and 2050 was 352372 and also predicted that the population of Akole city in 2021 is 23797 and 2050 was 97952 on the basis of high growth rate population 5%.

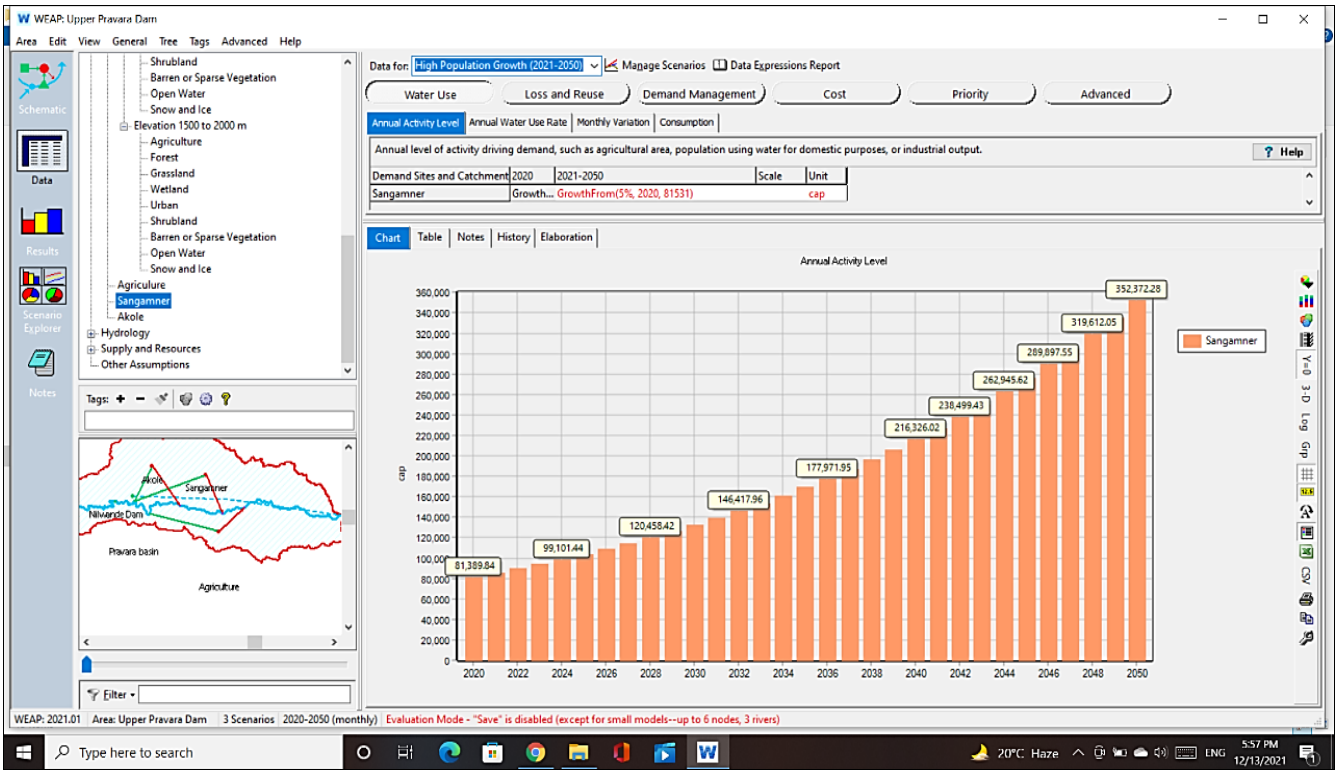

Fig 3: High Growth Population of Sangamner in WEAP Model

Table 4 presents the projected population for the next 30 years under both the reference and high population growth scenarios, respectively. Graph shows both Reference and High growth population curve of Sangamner and Akole city.

Table 4: Reference and High growth rate population of Sangamner and Akole

Sr. No	Year	Sangamner		Akole	
		Population on Reference Basis	Population on High growth rate Basis	Population on Reference Basis	Population on High growth rate Basis
1	2020	81389	81389	22627	22627
2	2021	83335	85607	23170	23797
3	2022	85326	89887	23726	24987
4	2023	87366	94382	24295	26236
5	2024	89454	99101	24878	27548
6	2025	91592	104057	25475	28925
7	2026	93781	109259	26087	30371
8	2027	96022	114722	26713	31890
9	2028	98317	120458	27354	33485
10	2029	100667	126481	28011	35159
11	2030	103073	132805	28683	36917
12	2031	105537	139446	29371	38763
13	2032	108059	146418	30076	40701
14	2033	110642	153739	30798	42736
15	2034	113286	161426	31537	44873
16	2035	115993	169497	32294	47116
17	2036	118766	177972	33069	49472
18	2037	121604	186871	33863	51946
19	2038	124510	196214	34675	54543
20	2039	127486	206025	35508	57270
21	2040	130533	216326	36360	60134
22	2041	133653	227142	37232	63141
23	2042	136847	238499	38126	66298
24	2043	140118	250424	39041	69613
25	2044	143467	262946	39978	73093
26	2045	146896	276093	40938	76748
27	2046	150406	289898	41920	80585
28	2047	154001	304392	42926	84615
29	2048	157682	319612	43956	88845
30	2049	161450	335593	45011	93288
31	2050	165309	352372	46092	97952

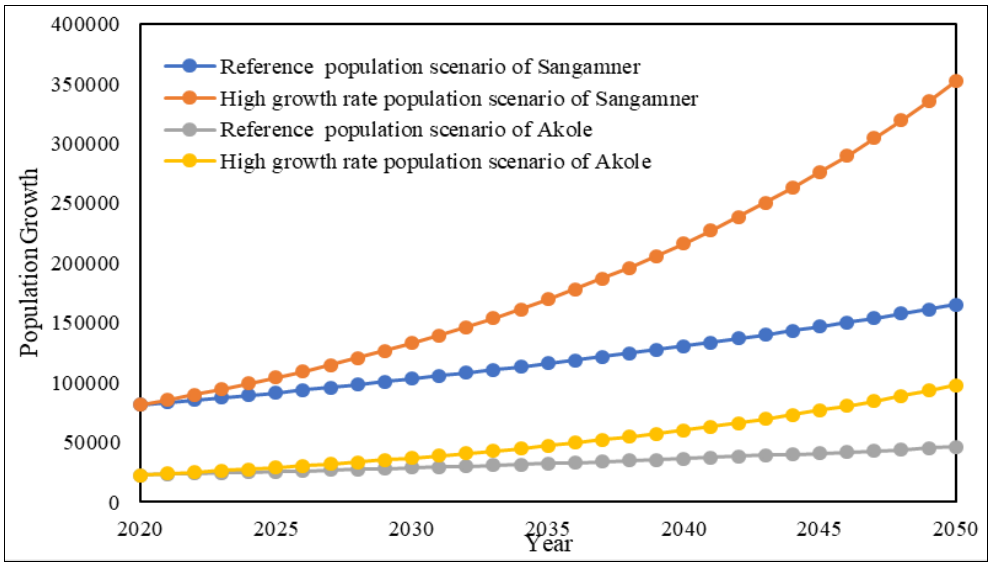

Fig 4: Schematic view of population scenarios of Sangamner and Akole

3.1.4. Population Growth of Sangamner and Akole on the basis of Reference Population and High Population growth Rate Scenario

The population growth of Sangamner and Akole based on reference population as 2.39% and 2.40% growth rate. Sangamner is a big city compare to Akole city that's why population is higher than Akole. Graph shows Sangamner and Akole population growth determined based on reference scenario.

The population growth of Sangamner and Akole based on high growth rate. This is calculated because if population increases suddenly then all requirements and demand are also increased. That's why with 5% growth rate considering predict population growth.

3.2. Demand of Water

In the current year (2020), WEAP estimated the annual domestic water demand for the urban areas within the catchment.

3.2.1 Sangamner

Figure 5 illustrates the WEAP model results for annual domestic water demand in Sangamner for the baseline year. The per capita demand for the Sangamner municipality was considered at 100 liters per person per day (l/p/c/d). The projections indicate that by 2050, domestic water demand is expected to rise to 6.03 Mm³ under the reference growth scenario and 12.85 Mm³ under the high population growth scenario.

able 3.2 provides a comparison of domestic water demand under the reference and high population growth scenarios. In the reference scenario, demand was 2.96 MCM in 2020 and is projected to rise to 6.03 MCM by 2050. Conversely, under the high population growth scenario, demand is expected to reach 12.85 MCM by 2050. The increase in domestic water demand for Sangamner city can be attributed to a relatively high population growth rate of 5% and a rise in per capita water consumption, estimated at 36.50 m³ per day by 2020.

3.2.2 Akole

Figure 5 displays the WEAP model results for annual domestic water demand in Akole for the baseline year. For Akole city, the per capita demand was considered at 70 liters per person per day (l/p/c/d). Projections indicate that by 2050, domestic water demand will rise to 1.174 Mm³ under the reference growth scenario and 2.496 Mm³ under the high population growth scenario.

Table 5 compares the domestic water demand in Akole under the reference and high population growth scenarios. In the reference scenario, demand was 0.576 MCM in 2020 and is projected to increase to 1.174 MCM by 2050. Under the high population growth scenario, demand is expected to rise significantly, reaching 2.496 MCM by 2050. The increase in domestic water demand for Akole city can be explained by the relatively high population growth rate of 5% and the rise in per capita water consumption, which was estimated at 25.50 m³ per day in 2020.

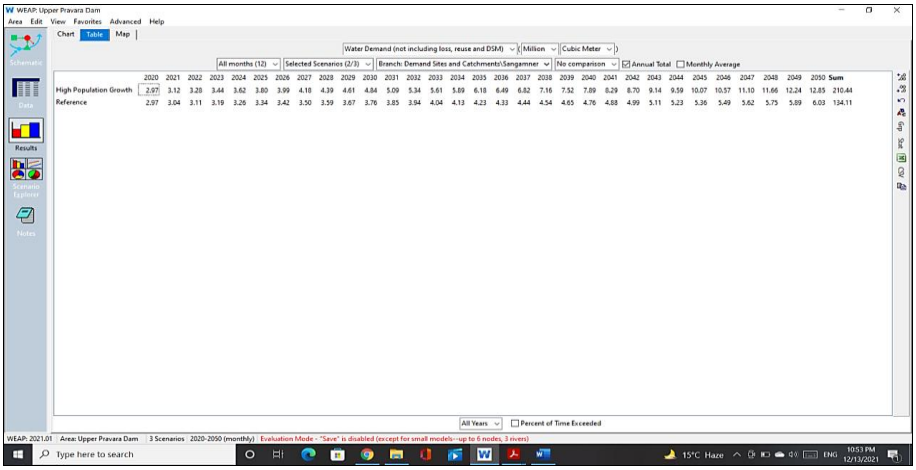

Fig 5: Annual water demand for Sangamner and Akole city in WEAP model

3.3. Supply of Water

3.3.1 Sangamner

In the high population growth scenario, adjustments to the water supply system were taken into consideration. Projections indicate that without improvements in water supply management, the region could face severe shortages by 2050. The results reveal that under the highest population growth rate, water demand in 2050 will be nearly double that of 2020. This highlights that population growth substantially increases the demand for water resources, even without accounting for potential climatic dry spells, which could further intensify water scarcity

3.3.2 Akole

Supply of water for Akole city was 0.61 MCM for the year 2020 at reference scenario and 1.24 MCM for 2050 and for the high population growth was 0.61 and 2.63 MCM respectively. Akole is small city as compare to Sangamner that's why the water demand and supply is very less.

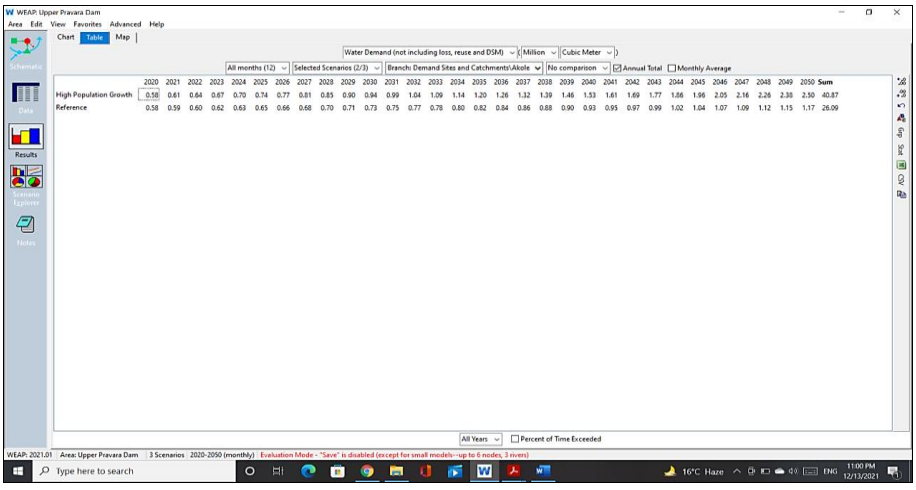

Fig 6: Annual water supply for Sangamner and Akole city in WEAP model

Table 5: Annual water demand and water supply for Sangamner and Akole city

Sr. No.	Year	Sangamner city				Akole city			
		Water Demand		Water Supply		Water Demand		Water Supply	
		Water Demand at 5% on HPGR (Mm^3)	Water Demand at 2.39% on reference (Mm^3)	Water Supply at 5% on HPGR (Mm^3)	Water Supply at 2.39% on reference (Mm^3)	Water Demand at 5% on HPGR	Water Demand at 2.39% on Reference	Water Supply at 5% on HPGR	Water Supply at 2.39% on Reference
1	2020	2.96	2.96	3.13	3.13	0.576	0.576	0.61	0.61
2	2021	3.12	3.03	3.29	3.2	0.606	0.59	0.64	0.62
3	2022	3.27	3.11	3.45	3.28	0.636	0.604	0.67	0.64
4	2023	3.44	3.18	3.62	3.35	0.666	0.619	0.7	0.65
5	2024	3.61	3.26	3.81	3.43	0.702	0.634	0.74	0.67
6	2025	3.79	3.34	4	3.52	0.737	0.649	0.78	0.68
7	2026	3.98	3.42	4.2	3.6	0.774	0.664	0.81	0.7
8	2027	4.18	3.5	4.41	3.69	0.812	0.68	0.86	0.72
9	2028	4.39	3.58	4.63	3.78	0.853	0.697	0.9	0.73
10	2029	4.61	3.67	4.86	3.87	0.896	0.713	0.94	0.75
11	2030	4.84	3.75	5.1	3.96	0.94	0.73	0.99	0.77
12	2031	5.08	3.84	5.35	4.05	0.987	0.748	1.04	0.79
13	2032	5.34	3.94	5.62	4.15	1.037	0.766	1.09	0.81
14	2033	5.61	4.03	5.9	4.25	1.1	0.784	1.15	0.83
15	2034	5.88	4.13	6.2	4.35	1.143	0.803	1.2	0.85
16	2035	6.18	4.23	6.51	4.45	1.2	0.823	1.26	0.87
17	2036	6.49	4.33	6.83	4.56	1.26	0.842	1.33	0.89
18	2037	6.81	4.43	7.18	4.67	1.323	0.862	1.39	0.91
19	2038	7.15	4.54	7.53	4.78	1.39	0.883	1.46	0.93
20	2039	7.51	4.65	7.91	4.9	1.459	0.904	1.54	0.95
21	2040	7.89	4.76	8.31	5.01	1.532	0.926	1.61	0.98
22	2041	8.28	4.87	8.72	5.13	1.609	0.948	1.69	1
23	2042	8.7	4.99	9.16	5.25	1.689	0.971	1.78	1.02
24	2043	9.13	5.11	9.62	5.38	1.774	0.994	1.87	1.05
25	2044	9.59	5.23	10.1	5.51	1.862	1.018	1.96	1.07
26	2045	10.07	5.35	10.6	5.64	1.955	1.043	2.06	1.1
27	2046	10.57	5.48	11.13	5.78	2.053	1.068	2.16	1.12
28	2047	11.1	5.61	11.69	5.91	2.156	1.093	2.27	1.15
29	2048	11.65	5.75	12.27	6.05	2.264	1.12	2.38	1.18
30	2049	12.24	5.88	12.89	6.2	2.377	1.147	2.5	1.21
31	2050	12.85	6.03	13.53	6.35	2.496	1.174	2.63	1.24

3.3.3 Combined water demand at Sangamner and Akole domestic site

Result shows high water demand for Sangamner than Akole, for reference scenario it having 2.97 Mm^3 water demand in 2020 and 6.03 Mm^3 for future water demand 2050. For Akole it was 0.57 Mm^3 in 2020 and 1.17 Mm^3 for 2050 water requirement as per population basis.

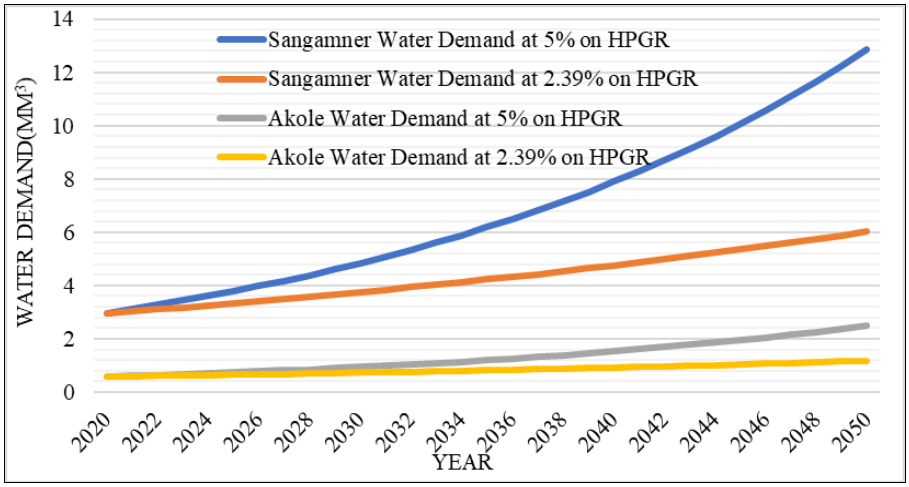

Fig 7: Annual combined water demand of Sangamner and Akole city at reference and high population growth scenario

3.3.4 Combined water supply at Sangamner and Akole domestic site

Result shows high water supply for Sangamner than Akole, for reference scenario it having 3.13 Mm^3 water supply in 2020 and 6.35 Mm^3 for future water supply 2050. For Akole it was 0.61 Mm^3 in 2020 and 1.24 Mm^3 for 2050 water requirement as per population basis.

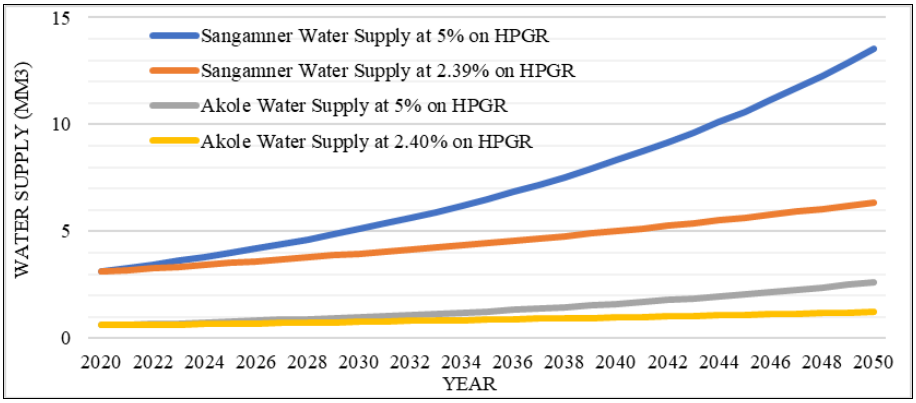

Fig 8: Annual combined water supply of Sangamner and Akole city at reference and high population growth scenario

4. Conclusion

The results of this study reveals that the water balance analysis of the Pravara Nilwande catchment up to the year 2050 was conducted and it is recommended that the results be used to assist in water resource decision making and planning by the decision makers in future. After the assessment using WEAP model it is concluded that, the observed irrigation water (2020) required was 2.37 Mm^3 and the predicted irrigation water demand for upcoming years (2050) is 2.02 Mm^3. The decrease in water requirement shows that the advanced technology and high urbanization (decrease in agricultural land) will be the part of irrigation which leads to the decrease in water demand in the future.

5. References

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